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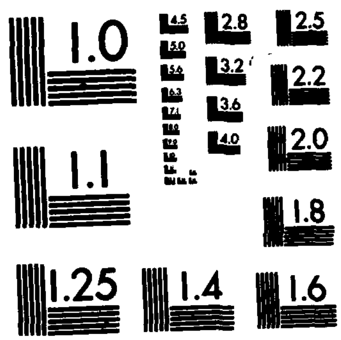

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Monterey, California

THESIS

AN INVESTIGATION OF A LAND COMBAT TACTICAL COMMANDER'S DECISION-MAKING PROCESS

by

Scott Kevin Johnson

October 1982

Thesis Co-Advisors: S. H. Parry
M. G. Sovereign

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An investigation was made of how two different experimental tools could be used to investigate an Army tactical commander's decision-making process. The procedure was to use a single decision; the Army battalion/task force commander's decision to mass supporting artillery on a trigger area/kill zone, and investigate the variables that affect the decision. The experimental tools used were a questionnaire, in which an experiment

on this decision was completed, and the interactive computer wargame, JANUS, which was described and investigated for its usefulness in analyzing tactical decisions.

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An Investigation of a Land Combat Tactical Commander's Decision-Making Process

by

Scott Kevin Johnson
Captain, United States Army
B.S., United States Military Academy, 1975

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
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ABSTRACT

An investigation was made of how two different experimental tools could be used to investigate an Army tactical commander's decision-making process. The procedure was to use a single decision; the Army battalion/task force commander's decision to mass supporting artillery on a trigger area/kill zone, and investigate the variables that affect the decision. The experimental tools used were a questionnaire, in which an experiment on this decision was completed, and the interactive computer wargame, JANUS, which was described and investigated for its usefulness in analyzing tactical decisions.

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I. INTRODUCTION

The purpose of this thesis is to investigate the Army tactical commander's decision-making process. This will be done by focussing on one tactical decision, and by describing the factors that went into making that decision, in the form of a mathematical model. In addition, the author will describe interactive computer wargame that adds realism to the experiment involving tactical decision-making, and will describe the use of the interactive wargame in analyzing tactical decisions.

The motivation for this investigation is the desire to come to grips with the problem of relating Command, Control, and Communications (C^3) to combat measures of effectiveness (MOE). By focussing on a single tactical decision and modelling it in terms of some variables that influence the decision, a statement can be made about the information needs of the decision-maker in making a decision. For example, if the decision to fire a tactical nuclear weapon was based on the size of an enemy force in a certain area, then the decision-maker would want to know the most timely and accurate information on the number of enemy in that area. The questions that might be asked concerning C^3 in this decision are what roles can C^3 play in making the decision: An information sensor? An information collector? An information communicator? A combination of all three? In addition, how well can C^3 be

measured in doing whatever it is supposed to do and perhaps can C^3 be modelled in terms of its utility as it contributes to combat effectiveness.

The author proposes possible solutions to these questions by first defining a command and control (C^2) system. The C^2 system will be described in terms of the well-known Lawson model and how the model relates to tactical decision-making. The emphasis will shift from the concept of a command and control system to a discussion of the present Army command and control system. More specifically the focus will be on a mechanized infantry or armor battalion and how the commander controls his forces. The battalion task force commander is required to make many decisions in combat. For the purpose of analyzing the environment in which he makes those decisions, one decision has been chosen to be analyzed: the task force commander's decision to mass artillery fires on a predesignated kill zone. The reasons for using this decision are: its relatively frequent use by tactical commanders; its relative lack of terrain dependence which sets it apart from other tactical decisions which often are very dependent on terrain. The impact of terrain on a decision is very difficult to measure since no single value can be applied to any terrain feature. The decision is made at a command level (battalion) where a C^3 system might be able to influence a decision. This is probably not the case of decision at any lower level than battalion.

Further experimentation is investigated by the possible use of an interactive computer wargame, JANUS. JANUS will be described in terms of its capabilities and its advantages and disadvantages relative to other experimental tools. An experiment to analyze this decision using a questionnaire was completed. The questionnaire portrayed a situation and varied the values of some variables believed to influence the decision. Based on the opinions of a sample of the population an analysis was completed on what influence the variables had on the tactical decision to mass artillery.

Finally a summary of the findings of this research is presented. It can be shown that understanding command, control and communications is difficult, and that one of the greatest problems in understanding is the lack of experimental tools to thoroughly investigate C^3. An attempt must first be made to define C^2 and how it can be analyzed.

II. COMMAND AND CONTROL AND MEASURES OF EFFECTIVENESS

A command and control system is normally oriented around a piece of hardware. This hardware, whether a computer, a radio, or a combination of the two, cannot be directly related to a combat measure of effectiveness on the battlefield. In short, a computer or communication system cannot directly destroy an enemy tank, and no acceptable method has been developed to relate the value of a new command and control system with respect to the value of a new combat system such as an M-1 tank. To understand the problem and find a solution, the following questions must be answered: What are measures of effectiveness? What is a command and control system? How can they be related to one another?

A. MEASURES OF EFFECTIVENESS AND MEASURES OF PERFORMANCE

If a command and control system is to be measured in terms of some effectiveness standard, it must be understood, in general, what is meant by effectiveness. Effectiveness means how well a system accomplishes its mission. The mission in the Army is defeating an enemy force in land combat. Therefore, the measure of effectiveness is how well a system contributes to the defeat of the enemy in land combat. A few examples of MOE are [Ref. 1: p. 4-141, 144, 145]:

1. number of enemy tanks destroyed per unit area
2. number of enemy tanks destroyed per number of tanks presented

3. the number of the enemy suppressed or delayed versus the total number of enemy.

Any number of other examples can be given, however, the predominant rationale behind any Army (MOE) is how well it reflects the outcome on the battlefield.

Closely related to the measures of effectiveness (MOE) are measures of performance (MOP) of a piece of equipment. A performance measurement can be thought of as a value on a scale that represents the capability of a piece of equipment. In terms of a command, control, communications system, examples of MOP's are:

1. bit rate,
2. size of memory,
3. signal to noise ratio,
4. power output.

A proposed C^3 system would have these and many other measures of performance. The dilemma of the Army is that new and improved hardware has improved MOP's over old systems. Improvements in performance, however, may not justify buying the equipment if the new equipment cannot measureably improve effectiveness on the battlefield.

B. A COMMAND AND CONTROL SYSTEM

Prior to discussing a command and control system, communications, the third part of the acronym C^3 is addressed. Communications is constantly needed by a tactical commander.

When a new communications systems is developed, it must meet the requirements specified in the required operational capability (ROC) guidelines. The MOE's are slightly different, since its contribution to defeating an enemy force, although not measurable in terms of the firepower like a tank, can be assumed of great importance. Communications is easily modelled and can be degraded for realism in a simulation or an interactive wargame. In approaching the problem of relating effectiveness of a C^2 system, the assumption of communications will be given in the experiment. Without a medium to transmit information, a C^2 system, especially one that incorporates automation, does not exist. However, the assumption will be addressed more formally later.

JC Pub. Number 1 defines:

> "Command control is the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of his mission."

It further states that:

> "A command and control system comprises the facilities, equipment, communications, procedures and personnel essential to a commander for planning, directing and controlling the operations of assigned forces pursuant to the mission assigned." [Ref. 2: p. 116]

A command and control system that is defined in this manner is not a single piece of hardware. It is also the human interaction with a machine, as well as human to human interaction. The complexity of the system is not only difficult to understand; it is almost impossible for a national level

decision-maker/fund-controller to decide exactly what the system encompasses, and how to improve it. Dr. Joel Lawson of the Naval Electronic Systems Command developed a simplified model of a C^2 process. Instead of attempting to model the entire system, he concentrated on its different functions. An illustration of the model is shown in Figure 1 [Ref. 3: p. 72].

In this example of a C^2 process, SENSE represents the sensor and intelligence information obtained from the combat environment. SENSE is the input that a decision-maker needs to address in the next step in the model. Intelligence and sensors have made the greatest improvements in the command and control process, because the advance in technology has been available. There are still many problems resulting from these advances, most notably fusing all the information available and eliminating redundant and unnecessary information.

COMPARE is simply the comparison of alternate courses of action. The desired state is normally the accomplishment of a mission directed by higher headquarters. Lawson developed a more complex model of the C^2 process to show the various levels of a military hierarchy. However, the basic model is the same at all levels.

DECIDE is the decision by a commander based on his comparison of alternate plans. Once the decision has been made, it is communicated to the subordinate forces who ACT on that

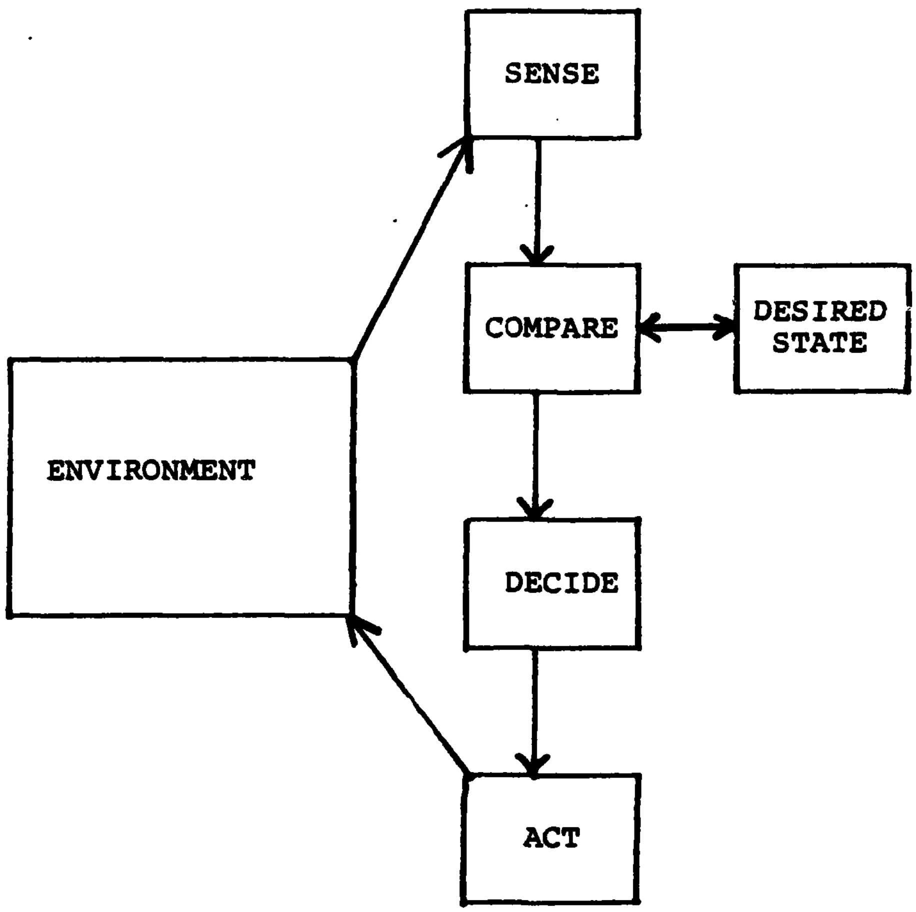

Figure 1. Lawson's Simplified Model

decision. The two arrows coming out of ACT refer to the result of the ACT on the ENVIRONMENT and the feedback that the sensors get based on the action.

Of all the functions in the Lawson model, ENVIRONMENT is the least understood analytically but the most important. The environment directly or indirectly influences every other step. It is not intuitive as to how one describes it and it is not easy to determine exactly how it influences the others.

However, if a command and control system is to be improved, the process of command and control must be well understood and the environment must be defined. It is the author's contention that the four factors: SENSE, COMPARE, DECIDE, ACT, make up a decision process. It is also the author's contention that the decision process developed by Lawson in his C^2 model can be analyzed in terms of the environmental variables that influence this process. This statement must be qualified, however, that this is only true of a single decision, not all tactical decisions. It is reasonable to assume that the variables of the environment are different for each decision. It follows that an analysis of Army tactical decision making should be done prior to designing an experiment to analyze the environmental parameters that affect the decision.

C. ARMY TACTICAL DECISION-MAKING

An Army tactical commander makes many different decisions during the course of a battle. It is extremely difficult to determine the value of each decision since all relate to the mission of the commander's unit. It can be concluded that if a commander has successfully accomplished his mission, then the decisions made contributed to the mission's success. It would appear on the surface that a tactical commander's decision that results in the enemy being destroyed or delayed, while the commander's own forces receive only light casualties, would mean that a decision or decisions were favorable.

Conversely, a decision that results in heavy casualties of a commander's own force would not be thought of as favorable. Yet, during the course of battle, if the heavy casualties taken by a subordinate unit resulted in a favorable maneuver to decisively defeat the enemy, perhaps the latter decision by the commander was not unfavorable. An effective decision is a difficult one to define and beyond the scope of this paper. For the purpose of this analysis, an effective decision will be one that defeats the enemy or disrupts his attack and a poor decision will be one in which the friendly forces suffer heavy casualties while allowing the enemy to continue the attack.

Having defined, in a relative manner, the effectiveness of a decision, the environmental variables that directly influence the decision-making process will be examined. Generally, the variables fall into four categories:

1. The mission given by higher headquarters.
2. The enemy force's strength and disposition.
3. The terrain in which the unit is located and fighting.
4. The commander's own forces available to him.

A tactical commander makes decisions based on any of the four environmental categories. Each decision is normally part of an overall operational plan; however, each part of the plan requires a decision that is more dependent on one

variable than others. It is entirely possible that one decision will affect another, but as a logical first step and for the purpose of analysis, each decision will be isolated and treated individually. Some decisions may be more difficult to model than others. It was previously stated that a decision is based on four categories. The human may react beyond these, based on a variable that does not fall into one of these categories, therefore, analysis becomes difficult. A typical example is the commander's "gut feeling" about a problem that has confronted him. He makes his decision based on his own feeling, in addition to the environmental factors. This "feeling" has historically separated some commanders from others. The predictability of such an action can only be done by examining each commander, not by analyzing the decision. An analysis of this type would have difficulty separating the commander from the decision. The commander's own personality would be difficult to distinguish from the variables that affect the situation that require the commander to make a decision. The only course, then, is to judiciously choose decisions that will not be influenced to a great extent by the individual commander's personal feelings, or to leave that out completely.

One decision must be chosen initially to model. This has been previously done with a fire/no fire decision by a tank commander [Ref. 4: p. 4]. The one chosen in this paper is a task

force commander's decision to mass his artillery fires on a pre-designated trigger area or kill zone. By doctrine, a battalion/task force commander has a single battery of artillery to support his forces. A battery is composed of eight 155 mm howitzers. Should it become necessary, however, additional batteries of artillery may be used on a pre-designated trigger/area. This would be called massing artillery, and is the decision of the ground commander to use his artillery in such a manner if he thinks it is appropriate. Massing artillery fires is a common task done by a task force commander, and can also be done at the company/team level depending on the mission. The variables involved in making the decision are potentially quantifiable. The experiment should be designed to find the values of those variables.

D. BATTALION/TASK FORCE STRUCTURE

A basic understanding of the structure of a battalion task force and the players involved in the decision to mass artillery fires is necessary prior to conducting any experiment or analysis. Figure 2 shows the organization of a battalion/task force.

The task force commander uses his operations officer (S-3) to coordinate the plan for direct fires (tanks, anti-tank missiles and infantry) and indirect fires. His principal controller of indirect fires is the fire support

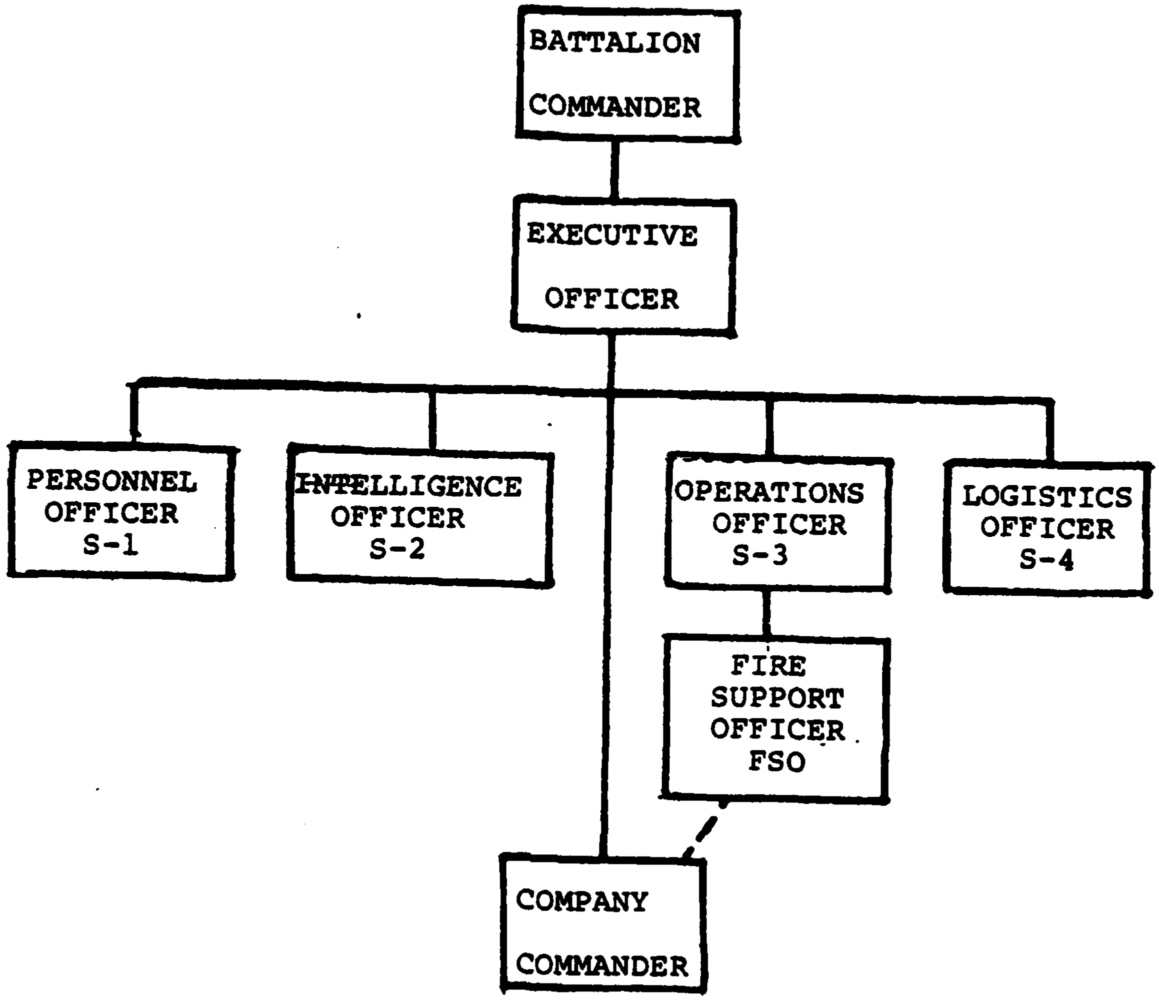

Figure 2. Task Force Organization

officer (FSO). It is the job of the FSO to insure that the task force commander has enough indirect fire from artillery to support his concept of operations. The FSO combines the fires from the organic 107 mm mortar platoon into his plan to support needs of the task force. Normal calls for fire come from the company/team's fire support team (FIST). The FIST requests indirect fires to support the team commander's

operations. The FSO receives the request, then transmits the request to an indirect fire unit depending on the type of target and the capability of artillery or mortars [Ref. 5].

The principle of a "kill zone" is to concentrate the direct and indirect fires on a specific area. This principle has long been the tactic used in an ambush, but several facts about the threat have led to its use on a much larger scale. The Warsaw Pact has developed its forces that force Army doctrine to adapt to counter the enemy development.

The enemy is a force of superior size who is attempting to move at a high rate of speed to build up momentum. The enemy also uses very centralized control of his forces and is willing to sustain losses to maintain the momentum of the attack. The kill zone is a means of controlling the task force fires to take advantage of the enemy's potential weaknesses.

The structure of a kill zone is normally a plot of ground around which the task force is deployed and against which the majority of direct fires can be directed. The FSO will be given the location and size of the kill zone and plot enough pre-planned targets to cover the area with a large volume of artillery. The task force commander will use the kill zone similar to that of an ambush kill zone in that he will normally wait until a large number of enemy vehicles are in the area, then fire on the enemy with a large volume of fire.

The purpose is to create a great deal of confusion among the enemy, as well as disrupting the attack, and taking the momentum away from the enemy's attack. The decision to mass artillery fires is made by the task force commander. It is his decision based on information that he receives from his subordinates as to when the attack should begin. The FSO and all supporting artillery are standing ready to fire once the decision is made.

The next chapter will focus on an experiment designed to investigate the variables that affect a commander's decision to mass artillery. The analysis will depend heavily on the judgment of experts in armored and infantry tactics.

III. <u>THE DECISION ANALYZED USING A QUESTIONNAIRE</u>

A. INTRODUCTION

The questionnaire is one of the experimental tools that may be used to analyze tactical decisions. The intent of this chapter is to show how a questionnaire can be used to quantify a tactical decision based on independent variables. The author conducted an experiment using a questionnaire as the experimental tool. The outline of the experiment, the data and the analyses of this data are included in this chapter, in Appendix A and B.

B. OBJECTIVE OF THE EXPERIMENT

The objective of the experiment is to obtain a mathematical model that describes the criticality of a designated trigger area for the massing of artillery fires.

C. THE APPROACH

The approach was to first obtain the independent variables for the questionnaire by querying several Army officers as to what factors would influence the decision to fire artillery on a designated trigger area. Each officer was given a tactical situation and asked to be the battalion commander in the situation. He was then asked to enumerate the factors that would influence his decision to fire. The results obtained were seventeen different variables for the situation,

essentially divided into three categories: enemy related, friendly forces related, and factors related to the physical environment. These seventeen factors were then used to obtain the independent variables for an experiment using a questionnaire.

The questionnaire was designed to be given to a sample population of Army officers familiar with battlefield tactics. For the purpose of simplification of the analysis, not all seventeen factors were used as variables in the questionnaire. An abbreviated version of the total experiment was conducted using four of the factors found in the survey as independent variables.

The experiment consisted of a questionnaire that depicted a tactical situation on a map and some information pertaining to the enemy and friendly situation. The subject analyzed the tactical situation, and responded to two questions concerning the situation. The responses to these two questions constitute the dependent variables of the experiment. As a result of the informal survey, the following factors were found that might influence a battalion commander to mass artillery fires on the trigger area.

1. Enemy Related

    (1) Size of the advanced guard.

    (2) Size and location of the Second Echelon.

    (3) Types of enemy vehicles.

    (4) The volume of fires on the main body of the friendly forces.

(5) The number of enemy forces in the trigger area.

(6) Size, activity, location, unit, time and equipment of all the enemy forces.

2. Friendly Forces Related

(1) The degree of camouflage of the friendly forces.

(2) Types of munitions available ("smart", chemical, etc.)

(3) Available personnel.

(4) Response capability of the available artillery.

(5) The degree of coordination with direct fire systems.

3. Environmental Related

(1) Size and location of the trigger area.

(2) Wind conditions.

(3) Time available for coordinated indirect fires.

(4) Daylight conditions.

(5) Visibility conditions.

From these seventeen variables, four were chosen for the questionnaire. They were chosen as a result of the frequency in which they appeared on the informal questionnaire. The independent variables and their possible values are described below.

D. THE INDEPENDENT VARIABLES AND THEIR POSSIBLE VALUES

1. The Number of Enemy Forces in the Trigger Area

(1) Less than 10 vehicles in the trigger area.

(2) 10-20 vehicles in the trigger area.

(3) 20-30 vehicles in the trigger area.

(4) Greater than 30 vehicles in the trigger area.

2. <u>The Intelligence Report on the Enemy Follow-on Force</u>

(1) A battalion to regimental size force less than 30 minutes from the task force's present positions.

(2) A battalion to regimental size force 30-60 minutes from the task force's present positions.

(3) A battalion to regimental size force greater than 60 minutes from the task force's present positions.

(4) No information is currently available about the follow-on enemy force.

3. <u>The Mission of the Friendly Force</u>

(1) Defend in Sector.

(2) Strongpoint Defense.

4. <u>The Response Time for the Supporting Artillery</u>

(1) Massed artillery on the trigger area in less than 2 minutes.

(2) Massed artillery on the trigger area in 2-4 minutes.

(3) Massed artillery on the trigger area in 4-6 minutes.

(4) Massed artillery on the trigger area in more than 6 minutes.

Several assumptions are made for this experiment. The reasons for these assumptions are numerous, however, the main reason is to insure that treatments were not in conflict with other variables not being analyzed. Clarity of the experiment is also important. The questionnaire must make clear to the subject what is being investigated, the assumptions, and an understanding of the sample trial. The assumptions for this experiment are discussed below.

E. ASSUMPTIONS OF THE EXPERIMENT

(1) The trigger area is within the maximum effective range of the friendly anti-armor weapons. Specifically the trigger area must be within 2000 meters for tanks and 3000 meters for heavy anti-tank weapons such as the TOW.

(2) The task organization for the friendly forces remains the same throughout the experiment. No additions or deletions will be made to the battalion's organization.

(3) Daylight conditions exist throughout the experiment. Visibility will not be inhibited by natural or artificial means.

(4) Enemy vehicles will be standard Warsaw Pact medium tanks, as well as BRDM or BMP equipped with SAGGER anti-tank missiles.

(5) The friendly forces are defending along the forward line of troops (FLOT). The covering force has passed through the friendly forces who are in a defensive posture, and are about to engage in their initial action of the battle.

(6) The enemy is attacking in classic Warsaw Pact echeloned formations. The lead element is normally a reconnaissance element, followed by the advanced guard, and then the main body.

(7) The friendly forces are at full strength in both personnel and equipment.

(8) The information given to the commander to make his decisions is not perfect information, but rather it is reported information from his own assets.

(9) Artillery ammunition is sufficient to allow the artillery to support the mission.

(10) The battalion in this situation has priority of fires.

(11) The direct support artillery has preplanned its fires on the trigger area.

(12) The trigger area/kill zone has been defined in the battalions operation's order as the battalion's fire control measure.

F. EXPERIMENTAL DESIGN

The experiment was designed to investigate the criticality of the information as to whether a tactical decision maker would mass artillery fires and whether he would actually fire or not based on the four variables previously described. A full factorial design was chosen so that each of the treatments might be analyzed and interactions among variables could be investigated. Since three of the four variables had four levels, some transformations were required to put the treatments into the desired HIGH-LOW format through creation of pseudo variables.

The technique used to transform the four levels of each variable was to create two pseudo variables, each with a value of HIGH and LOW. Figure 3 shows how the four levels of "Number of Vehicles in the Trigger Area/Kill Zone" are transformed.

NUMBER OF VEHICLES

	B_{LOW}	B_{HIGH}
A_{LOW}		
A_{HIGH}		

INTELLIGENCE

	D_{LOW}	D_{HIGH}
C_{LOW}		
C_{HIGH}		

MISSION

E_{LOW}		
E_{HIGH}		

RESPONSE TIME

	G_{LOW}	G_{HIGH}
F_{LOW}		
F_{HIGH}		

Figure 3. Matrix of Transformation.

The same procedure is used for the variables "The intelligence report on the enemy follow-on forces" and "The response time for the supporting artillery".

INTELLIGENCE

	D LOW	D HIGH
C LOW	Less than 30 minutes	Greater than 60 minutes
C HIGH	30-60 minutes	No information available

MISSION

E LOW	Defend in Sector
E_{HIGH}	Strong-point

RESPONSE TIME

	C_{LOW}	G_{HIGH}
F_{LOW}	0-2 minutes	4-6 minutes
F_{HIGH}	2-4 minutes	greater than 6 minutes

If one examines the technique of creating pseudo variables, it is evident that difficulties in interpretation of interaction effects among variables may arise. The technique used to analyze interactions was to use a mean value differential analysis. This technique will be discussed later in this chapter [Ref. 6: p. 106].

The experiment has been designed so that the seven variables are transformed from four variables (three with four levels and one with two levels) to an experiment with seven variables each with two levels. The criteria for a full factorial design experiment have now been met.

A full factorial experiment required 27 or 128 treatments. Each of the treatments was applied to the questionnaire by using the transformation matrix shown in Figure 3.

An example might be the treatment: A E F G. This implies that the values for each of seven treatments are: A_{HIGH} B_{LOW} C_{LOW} D_{LOW} E_{HIGH} F_{HIGH} G_{HIGH}. Using the transform tables, the questionnaire depicts the values of the four variables as: 10-20 vehicles in the trigger area, a battalion to regimental size force less than 30 minutes from the task force's present positions, the mission of the task force is to defend in sector, and the response time of the artillery is greater than six minutes.

G. DATA COLLECTION

Three replications of each of the 128 treatments were collected during the experiment for a total of 384 data points. The treatments were divided up in a random order and given to 24 subjects. Each subject had sixteen different situations, without replication. Selected individuals were given a duplicate treatment to one of their sixteen to check for consistency in their decisions. Each subject was given a general situation which included the assumptions, a map and tactical overlay, and the sixteen (or seventeen) situations. The subject was asked to analyze the situation and specific values of the variables. He was then asked two questions: the first was to assess the criticality of the trigger area using information from the four variables as to whether he would mass artillery; the second question was whether he would mass fires or not. An example of a typical set of questionnaires with the general situation is given in Appendix A.

The subjects were made up of Army senior enlisted men and officers ranging in grade from E-6 to 0-5. The only restriction was to require that all personnel be infantry, armor or artillery by specialty. This was to insure that the data base came from subjects with expertise in Army battalion level tactics. The subjects were given unlimited time to perform the test. This may or may not have influenced the results. Unlimited time may have caused interest to be lost in the

latter treatments. On the other hand, had a time limit been set, time may have become a variable in the experiment with no ability to analyze its effect. The results of the data collection are given in Appendix B.

H. DATA ANALYSIS

The motivation for this experiment was to investigate the effect of four variables on a specific decision. The data collected for this experiment may be analyzed in great depth and thoroughness from several different perspectives. The author chose to analyze two specific areas and to limit the scope of the analysis to the effects on only one of the dependent variables.

The dependent variable analyzed is the index of criticality. The treatments that significantly affected this dependent variables are investigated and a possible explanation for their significance is discussed. A regression analysis of the significant factors on this dependent variable has been completed and a model is presented which describes the influence of the independent variables on this decision.

The computer program used for analyzing the data was written for a thesis by Glenn J. Broussard [Ref. 4: p. 13] who used a fractional factorial design to investigate the fire/no fire decision of a tank commander based on eleven variables. CPT Broussard's analysis goes into great detail on the principles behind each of the specific analysis techniques. Detailed explanations for each analysis of variance can be found in Broussard's thesis.

The purpose of this analysis is to investigate a decision in terms of four variables. The influence of these variables can be described in quantitative terms. The significance of this capability may stimulate research on quantifying decision-making using other tools for analysis such as computer simulations or interactive computer wargames.

1. Tools of Analysis and Transformations

The primary tool used in this analysis was the Analysis of Variance (ANOVA). The assumptions of the ANOVA are:

(1) Observations are drawn from normally distributed populations.

(2) Observations represent random samples of the population.

(3) Variances of the population are equal.

It is assumed that the observations represent random samples of the populations. The first assumption implies that the errors associated with the observations are also normally distributed. This was tested using the Kolmogorov-Simnov 1 Sample Test. The assumption of equal variances was tested using Barlett's test of homogeneity of variance. The hypothesis tests for both of these assumptions are shown below.

Assumption 1:

H_o: $e_1 = e_2 = e_3 = e_{128}$ for all treatments are distributed $N(0, 6^2)$

H_1: H_0 is false.

Assumption 2:

H_0: $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \ldots \sigma_{128}^2 = \sigma_e^2$

H_1: Some σ^2 are not equal.

The criterion for rejection of both assumptions is if the right hand tail probability associated with the test statistic calculated for each test is less than .05. The results of these tests are shown in Table I. Based on the results of the Kolmogorov-Simnov 1 Sample test and Bartletts test the null hypothesis was accepted, since the results of both test were greater than the .05 test statistic used in the evaluation of the tests.

Recall that the random sample of 24 subjects crossed various lines of rank and specialty. It was apparent that difficulties might occur in the differences in the scaling of the dependent variable between subjects. CPT Broussard used a common technique that helps to resolve the scaling problems that could occur in the data [Ref. 4: p. 66]. The transformation was to rescale the data from 0 to 100 to a scale of 0 to 1, with the minimum observation set to zero. In addition, other transformations were tried to allow the data to conform to the assumptions of the ANOVA. Among those tried were:

1. $y' = y$
2. $y' = y^2$
3. $y' = y$
4. $y' = \ln y$

TABLE I

```
****************************************************
* STATISTICS FOR TESTING ANOVA ASSUMPTICNS *
****************************************************

BARTLETT TEST FCR HOMOGENEITY OF CELL VARIANCES
-----------------------------------------------
    M / C   (CHI SQUARE) :      114.3362
    CEGREES OF FREEDOM :          127
    PROB(X .GT. M/C) :    0.782525

F MAX RATIO
-----------
    S**2(MAX) / S**2(MIN) :     211.0000
    G (NUMBER OF CELLS) :         128
    CEGREES OF FREEDOM FCR EACHS :           2

KS TEST FOR NORMALITY ASSUMPTION
--------------------------------
    KS STATISTIC (DMAX) : 0.061365
    NUMBER OF POINTS :         128
    PROB(X .GT. KS) :  0.720764
```

TREATMENT	MEAN OF OBSERVED VALUES	PREDICTED VALUE	RESIDUAL	
ABD	0.6500	0.9040	-0.2540	**
ADEF	0.4300	0.6762	-0.2462	**
ABCFG	0.6667	0.8883	-0.2217	**
ACF	0.5667	0.7812	-0.2146	**
AE	0.4667	0.6779	-0.2112	**
ABCG	0.7300	0.9294	-0.1994	
ABEF	0.7233	0.9192	-0.1958	
ACFG	0.6000	0.7802	-0.1802	
ACDFG	0.5833	0.7385	-0.1552	
ABDEG	0.7000	0.8365	-0.1365	
BCEG	0.6133	0.7408	-0.1275	
ABCF	0.7633	0.8894	-0.1260	
ABCDFG	0.7233	0.8467	-0.1233	
CDE	0.3767	0.4969	-0.1202	
ACEF	0.6167	0.7342	-0.1175	
ABEFG	0.9167	1.0327	-0.1160	
ABDE	0.7267	0.8375	-0.1108	
F	0.4267	0.5283	-0.1017	
ADG	0.5867	0.6823	-0.0956	
ABCDG	0.8000	0.8877	-0.0877	
A	0.7500	0.8375	-0.0875	
ACDEG	0.6467	0.7335	-0.0869	
ABCE	0.8900	0.9754	-0.0854	
CDG	0.4633	0.5440	-0.0806	
ACDF	0.6667	0.7396	-0.0729	
BCD	0.4667	0.5385	-0.0719	
ACG	0.7500	0.8212	-0.0712	
AG	0.6533	0.7240	-0.0706	
ACDE	0.6633	0.7325	-0.0692	
ACDEFG	0.5133	0.5790	-0.0656	
ACEFG	0.5567	0.6206	-0.0640	
ABDF	0.7667	0.8304	-0.0638	
AEG	0.6133	0.6769	-0.0635	
CDEFG	0.2833	0.3433	-0.0600	
ACEG	0.7167	0.7752	-0.0585	
ABEG	0.8200	0.8781	-0.0581	
ABCEFG	0.9333	0.9910	-0.0577	
AEFG	0.7767	0.8315	-0.0548	
DEF	0.3867	0.4406	-0.0540	
CEFG	0.3333	0.3850	-0.0517	
ABC	0.7667	0.8158	-0.0492	
ABF	0.8233	0.8721	-0.0487	
ADEG	0.5867	0.6352	-0.0485	
BDEF	0.5933	0.6419	-0.0485	
ABDFG	0.7833	0.8315	-0.0481	
ABCEG	0.9333	0.9765	-0.0431	
E	0.4000	0.4423	-0.0423	
ABCDEG	0.8933	0.9348	-0.0415	
BCDEF	0.6167	0.6581	-0.0415	
AC	0.6667	0.7077	-0.0410	
CDF	0.4667	0.5040	-0.0373	
ABE	0.8433	0.8792	-0.0358	
ABCDF	0.8133	0.8477	-0.0344	
ACDG	0.7467	0.7796	-0.0329	
AFG	0.7333	0.7650	-0.0317	

** INDICATES RESIDUAL MAGNITUDE EXCEEDS 2(TWO) STANDARD DEVIATIONS

TREATMENT	MEAN CF OBSERVED VALUES	PREDICTED VALUE	RESIDUAL
ABCG	0.7667	0.7904	-0.0238
ABCDE	0.9133	0.9338	-0.0204
ACD	0.6467	0.6660	-0.0194
AB	0.9267	0.9456	-0.0190
D	0.5500	0.5602	-0.0102
ABFG	0.8667	0.8731	-0.0065
ADEFG	0.7833	0.7898	-0.0065
ABCEF	0.9300	0.9354	-0.0054
ABCDEF	0.8900	0.8938	-0.0038
ADE	0.6333	0.6362	-0.0029
C	0.4700	0.4721	-0.0021
ABCEFG	0.8200	0.8219	-0.0019
DEFG	0.5533	0.5542	-0.0008
BCEF	0.7000	0.6998	0.0002
BCFG	0.6533	0.6527	0.0006
CD	0.4333	0.4304	0.0029
G	0.4933	0.4883	0.0050
ABCD	0.7800	0.7742	0.0058
BEFG	0.8033	0.7971	0.0063
BEF	0.6900	0.6835	0.0065
ACE	0.7833	0.7742	0.0092
BF	0.6500	0.6365	0.0135
AD	0.8133	0.7958	0.0175
DF	0.5133	0.4867	0.0267
CG	0.6133	0.5856	0.0277
BCDEFG	0.5800	0.5446	0.0354
BCDF	0.6500	0.6121	0.0379
BCEFG	0.6267	0.5862	0.0404
BDEFG	0.7967	0.7554	0.0413
DFG	0.5300	0.4877	0.0423
BCDG	0.7000	0.6521	0.0479
AEF	0.7667	0.7179	0.0488
ABCDEFG	0.8300	0.7802	0.0498
ABG	0.8833	0.8321	0.0513
FG	0.5833	0.5294	0.0540
BE	0.7000	0.6435	0.0565
BG	0.6533	0.5965	0.0569
BEG	0.7000	0.6425	0.0575
ADFG	0.7833	0.7233	0.0600
(1)	0.6633	0.6019	0.0615
ABDEF	0.9400	0.8775	0.0625
DE	0.4633	0.4006	0.0627
DEG	0.4633	0.3996	0.0638
EFG	0.6667	0.5958	0.0708
BDG	0.6267	0.5548	0.0719
BCG	0.7667	0.6937	0.0729
BDE	0.6800	0.6019	0.0781
BDF	0.6800	0.5948	0.0852
BDFG	0.6833	0.5958	0.0875
ADF	0.8167	0.7223	0.0944
BDEG	0.7000	0.6008	0.0992
AF	0.8700	0.7640	0.1060
ACDEF	0.8033	0.6925	0.1108
CDEG	0.6100	0.4979	0.1121
BC	0.6967	0.5802	0.1165

** INDICATES RESIDUAL MAGNITUDE EXCEEDS 2(TWO) STANDARD DEVIATIONS

TREATMENT	MEAN OF OBSERVED VALUES	PREDICTED VALUE	RESIDUAL	
CE	0.6600	0.5385	0.1215	
CDEF	0.5800	0.4569	0.1231	
EG	0.5667	0.4412	0.1254	
CDFG	0.6333	0.5029	0.1304	
CEF	0.6300	0.4985	0.1315	
BCDFG	0.7500	0.6110	0.1390	
BCE	0.8800	0.7398	0.1402	
BCF	0.8033	0.6537	0.1496	
BCDEG	0.8500	0.6992	0.1508	
B	0.8633	0.7100	0.1533	
CEG	0.6967	0.5396	0.1571	
BD	0.8433	0.6683	0.1750	
BFG	0.8367	0.6375	0.1992	
DG	0.6467	0.4467	0.2000	
EF	0.6833	0.4823	0.2010	
BCDE	0.9167	0.6981	0.2185	**
CFG	0.8167	0.5446	0.2721	**
CF	0.8367	0.5456	0.2910	**

** INDICATES RESIDUAL MAGNITUDE EXCEEDS 2 (TWO) STANDARD DEVIATIONS

5. $y' = \ln y$

6. $y' = \arcsin y$

7. $y' = \arcsin \sqrt{y}$

Several of these transformations allowed the data to favorably agree with the ANOVA assumptions. It was decided, however, not to use any of the transformations mentioned since none of those tried caused the data to more favorably agree with the assumptions.

The resulting conclusions are based on the data itself and not additional transformations, other than for scaling.

I. ANALYSIS OF TREATMENT EFFECTS

The generalized ANOVA (Table II) for the experimental shows the sum of squares and the degrees of freedom for each of the sources. It also shows the mean square of the residual which will be used in computing F-statistics in the following treatment ANOVA.

The treatment ANOVA in Table III depicts the results of some different computations to be used in the analysis of the results. There were no aliases in this experiment, which is the reason for a blank in this column. The mean square for each term and the computed F-statistics are self-explanatory. In conducting this analysis, the difference between the fact that a treatment is significant and the effect of that treatment on the result must be clarified. A factor is significant if the sum of squares when that treatment is high plus the sum of squares when that treatment is low divided by the degrees of

TABLE II

GENERALIZED ANOVA

SOURCE	SS	DF	MS
MEAN	181.775	1	
BETWEEN BLOCKS & REPS	0.0	2	
REPLICATIONS	1.739	2	
BLOCKS	-0.000	0	
RESIDUAL(BETWEEN)	0.000	0	0.0
WITHIN BLOCKS & REPS	16.293	381	
TREATMENTS	7.941	127	
RESIDUAL(WITHIN)	8.352	254	0.033
TOTAL	199.807	384	

TABLE III

TREATMENT ANOVA

SOURCE	2/3 FI ALIASE	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)	
A		1	0.118	1.332	40.523	0.000	****
A		1	0.118	1.332	40.523	0.000	****
B		1	0.155	2.297	69.859	0.000	****
C		1	-0.006	0.003	0.103	0.749	
D		1	-0.042	0.167	5.069	0.025	**
E		1	-0.005	0.003	0.086	0.770	
F		1	0.002	0.000	0.010	0.919	
G		1	-0.001	0.000	0.005	0.942	
FG		1	-0.002	0.000	0.007	0.933	
EG		1	-0.002	0.000	0.007	0.933	
EF		1	-0.013	0.016	0.487	0.486	
EFG		1	-0.008	0.007	0.208	0.649	
DG		1	0.013	0.015	0.464	0.496	
DF		1	-0.001	0.000	0.006	0.937	
DFG		1	-0.002	0.000	0.007	0.933	
DE		1	0.005	0.002	0.061	0.805	
DEG		1	-0.003	0.001	0.023	0.879	
DEF		1	-0.007	0.005	0.138	0.711	
CG		1	-0.025	0.060	1.825	0.178	
CF		1	-0.041	0.158	4.794	0.029	**
CFG		1	-0.057	0.315	9.583	0.002	****
CE		1	0.032	0.101	3.064	0.081	
CEG		1	-0.056	0.304	9.238	0.003	****
CEF		1	-0.057	0.309	9.409	0.002	****
CD		1	0.002	0.000	0.014	0.906	
CDG		1	0.009	0.008	0.234	0.629	
CDF		1	0.007	0.005	0.160	0.690	
CDE		1	0.009	0.007	0.218	0.641	
BG		1	-0.004	0.002	0.046	0.831	
BF		1	-0.014	0.018	0.544	0.462	
BFG		1	0.022	0.045	1.371	0.243	
BE		1	0.047	0.208	6.330	0.012	**
BEG		1	-0.000	0.000	0.001	0.982	
BEF		1	0.002	0.000	0.007	0.933	
BD		1	0.014	0.018	0.544	0.462	
BDG		1	0.005	0.002	0.061	0.805	
BDF		1	0.014	0.020	0.595	0.441	
BDE		1	0.022	0.045	1.357	0.245	
BC		1	0.001	0.000	0.003	0.955	
BCG		1	-0.003	0.001	0.034	0.853	
BCF		1	0.004	0.001	0.037	0.848	
BCE		1	0.011	0.012	0.356	0.551	
BCD		1	0.022	0.045	1.371	0.243	
AG		1	-0.011	0.013	0.383	0.536	
AF		1	0.008	0.006	0.178	0.673	
AFG		1	-0.005	0.003	0.086	0.770	
AE		1	0.015	0.023	0.685	0.409	
AEG		1	0.016	0.023	0.713	0.399	
AEF		1	0.028	0.077	2.327	0.128	
AD		1	0.024	0.054	1.632	0.203	
ADG		1	-0.018	0.032	0.959	0.328	
ADF		1	0.023	0.053	1.604	0.207	
ADE		1	-0.004	0.002	0.059	0.809	
AC		1	-0.009	0.007	0.213	0.645	

** INDICATES THAT P(X.GT.F) IS LESS THAN .05
**** INDICATES THAT P(X.GT.F) IS LESS THAN .01

SOURCE	2/3 FI ALIASE	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)
ACG		1	-0.003	0.001	0.023	0.879
ACF		1	-0.031	0.090	2.738	0.099
ACE		1	0.028	0.077	2.344	0.127
ACD		1	0.026	0.063	1.917	0.167
AB		1	-0.010	0.010	0.304	0.582
ABG		1	0.012	0.013	0.405	0.525
ABF		1	0.014	0.020	0.603	0.438
ABE		1	0.018	0.032	0.959	0.328
ABD		1	-0.020	0.039	1.192	0.276
ABC		1	0.018	0.031	0.948	0.331

** INDICATES THAT P(X.GT.F) IS LESS THAN .05
*** INDICATES THAT P(X.GT.F) IS LESS THAN .01

freedom for each, minus the grand mean divided by the total degrees of freedom, is greater than the F-statistic computed for that treatment. The effect of a treatment, for example, with one variable (main effect treatment) is simply the mean value of the treatment when the value is HIGH minus the mean value of the treatment when its value is LOW, or simply stated: Effect = $\bar{A}_{HIGH} - \bar{A}_{LOW}$

The difficulty in the analysis comes when trying to explain the effects of a treatment with a two or three variable interaction that has been found to be significant. The only means of analyzing this effect is to use a technique called mean value differential analysis [Ref. 5: p. 106]. A complete analysis using this technique is beyond the scope of this thesis. For the purposes of understanding how a two or three factor interaction might be analyzed, an example is given using a significant three-factor interaction found in this analysis.

The basic thrust of this analysis is to determine the mean value of the responses for specified high and low values of the variables in the interaction term, averaged over high and low values of all other variables. The procedure begins by computing the mean response of the first variable in the interaction at its high and low level. Next, the mean response of the second variable is computed at its high and low level for each level of the first variable. This process is continued for all factors in the interaction. This process is best

demonstrated by an example. Using the significant interaction treatment CFG, a mean value differential analysis will be conducted. The mean value for C_{HIGH} is: 0.6842. The mean value for C_{LOW} is: 0.5412. The mean values for F_{HIGH} and F_{LOW} will be computed given C is HIGH or C is LOW. The same is true for the mean values of G_{HIGH} and G_{LOW} given that F is HIGH and F is LOW. Figure 4 will explain this procedure further.

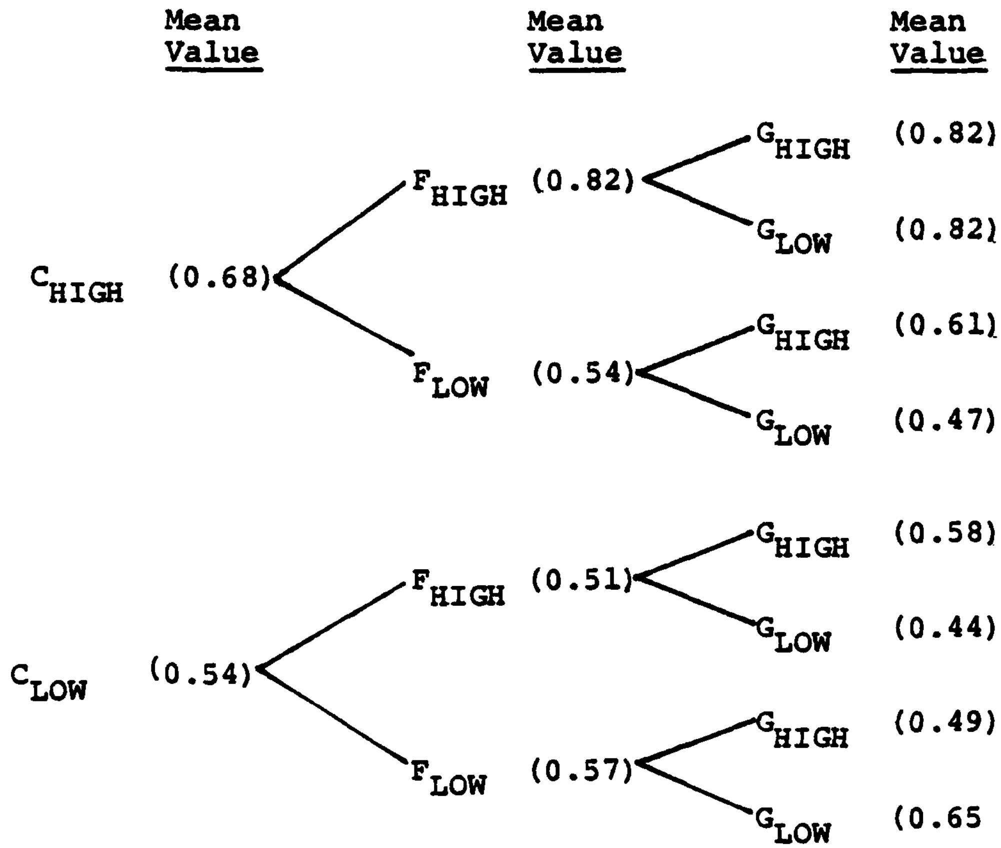

Figure 4. Mean-Value Differential Diagram.

Each of the mean values for the different variables represents the mean value of that variable, given that the value of its predecessor is HIGH or LOW. For example, the mean value of 0.65 for G_{LOW} is the mean value for G_{LOW} given F_{LOW} and C_{LOW}. Another example, the mean value is 0.82 for both G_{HIGH} and G_{LOW} given F_{HIGH} and C_{HIGH}.

Interpreting the effects on interaction treatments can be done using mean value differential analysis. If, for example, C is HIGH, the variable F will have a stronger effect on variable C_{HIGH} when the value of F is HIGH also. This is because the mean value of F_{HIGH} given C_{HIGH} is greater than the mean value for F_{LOW}. On the other hand, because G_{HIGH} and G_{LOW} have the same value given F_{HIGH} and C_{HIGH}, this means G will have no stronger effect on F_{HIGH} for either F_{HIGH} or G_{LOW}.

This is the method used to determine the effects of the significant interaction treatments. A detailed analysis using mean value differential analysis will not be done, however, this example is shown to introduce the proper way to analyze the effects of significant two or three factor interactions.

Several variables were found to be significant at the 0.05 level and a few at the 0.01 level. Only two and three factor interactions were investigated in this analysis. As shown with mean value differential analysis, interpretation of the effects of two and three factor interactions is difficult. Beyond three factor would not only be difficult to analyze

but a lengthy and difficult process using mean value differential analysis. The significant factors at the 0.05 level are: A, B, D, CF, CFG, CEG, CEF and BE.

In analyzing the effect of the significant factors it was stated that the effect for the main effect treatments is the difference in the mean value of the HIGH and LOW levels for that main treatment. A positive difference is interpreted to influence the index of criticality to a higher value. The information was interpreted by the subject to be more favorable in his inclination to call for massed artillery on the trigger area/kill zone. A negative effect means a negative difference in the mean values and has the opposite interpretation of the positive effect. The index of criticality will tend to move downward.

1. <u>An Analysis of the Simple Main Effects</u>

Three of the main effects were found to be significant: A, B, D. A and B were found to have positive effects while D has a negative effect. In the design of the experiment, some of the variables were grouped in pairs to provide a means for analysis of a single variable with four levels. For example, the factors A and B are pseudo factors whose high and low values represent four levels of the single variable "number of vehicles".

Although this may be convenient for design, the results of the analysis may be difficult to interpret because one of the two variables may be lacking in definition. Such is the case for the variable, A.

A was found to be significant, however, the possible values for A as shown in Figure 3 are:

A_{HIGH} = less than 10 vehicles in the kill zone

or = 20-30 vehicles in the kill zone

A_{LOW} = 10-20 vehicles in the kill zone

or = more than 30 vehicles in the kill zone

No clear physical explanation is possible to explain the implication of the mean value of A being positive.

The treatment B also had a positive effect, but unlike the treatment, A, the positive mean value can be explained. The possible values for B from Figure 3 are:

B_{HIGH} = 20-30 vehicles in the kill zone

or = more than 30 vehicles in the kll zone

B_{LOW} = 10-20 vehicles in the kill zone

or = less than 10 vehicles in the kill zone

Clearly, it can be seen that a value of twenty vehicles is a separation value of the treatment. It can be concluded that if more than 20 vehicles are in the kill zone, the index of criticality is 0.155 higher than when less than 20 vehicles are present (see Table II).

A similar condition exists for treatment D. The values of D from Figure 4 are:

D_{HIGH} = follow-on force is greater than 60 minutes away

or = no information is available

D_{LOW} = the follow-on force is 30-60 minutes away

or = the follow-on force is less than 30 minutes away

The value that is the difference between D_{HIGH} and D_{LOW} is 60 minutes. It can be concluded that a value of greater than 60 minutes results in a decrease in the index of criticality of 0.042 relative to a time of less than 60 minutes.

2. The Analyses of the Two and Three Factor Interactive Effects

As stated earlier the analysis of two and three factor interactions requires further analysis and is beyond the scope of this thesis. It must be concluded that there are significant negative effects between the intelligence available and artillery response time (CF and CFG); between available intelligence, the mission of the friendly forces and artillery response time (CEF and CEG) and a positive effect on the interaction between the number of vehicles in the trigger area/kill zone the mission of the friendly forces (BE).

3. Analysis of the Selected Model

Table IV shows the results of the regression analysis. Variance accounted for by regression or the "R^2" term is approximately 0.44. Variance accounted for by the selected model is 0.35619. A variance of 0.44 is judged to be fairly reasonable considering the subjective nature of both the treatments and the dependent variables. The resulting model based on the statistics in Table V is the following:

$$\begin{aligned} \text{Index of Criticality (IC)} &= 0.68802 \\ &+0.05891X_1 + 0.07734X_2 - \\ &\ 0.02083X_4 - 0.02026X_3X_6 - \\ &\ 0.02865X_3\,X_6\,X_7 - 0.02812X_3X_5X_7 \\ &-0.02839X_3\,X_5\,X_6 + 0.02328X_2X_5 \end{aligned}$$

TABLE IV

GENERAL ANOVA FOR SELECTED MODEL

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F STATISTIC	PROB (X.GT.F)	
MEAN	181.775	1	181.775			
REGRESSION(TERMS)	6.423	9	0.714	21.703	0.0	***
RESIDUAL	11.609	374				
LACK OF FIT	1.518	118	0.013	0.391	1.0000	
SOURCES(BETWEEN)	1.739	2				
ERROR(ADJUSTED)	8.352	254	0.033			
TOTAL	199.807	384				

** INDICATES SIGNIFICANCE AT .05
**** INDICATES SIGNIFICANCE AT .01

PERCENT VARIABILITY THAT CAN BE EXPLAINED BY REGRESSION: 44.0400

PERCENT VARIABILITY EXPLAINED BY THE SELECTED MODEL: 35.6190

SAMPLE MULTIPLE CORRELATION COEFFICIENT:0.5968

STANDARD DEVIATION OF RESIDUALS: 0.1048

MEAN RESIDUAL MAGNITUDE: 0.0818

MAXIMUM DEVIATION BETWEEN PREDICTED & OBSERVED VALUES: 0.29100+00

PERCENTAGE OF OBSERVED VALUES FALLING
WITHIN 1(ONE) STANDARD DEVIATION OF REGRESSION LINE: 69.53%

PERCENTAGE OF OBSERVED VALUES FALLING
WITHIN 2(TWO) STANDARD DEVIATIONS REGRESSION LINE: 93.75%

NUMBER OF RESIDUALS WHOSE MAGNITUDE IS GREATER
THAN 2(TWO) STANDARD DEVIATIONS: 8

TABLE V

STATISTICS FOR SELECTEC MCDEL

VARIABLE	REGRESSION COEFFICIENT	SUM OF SQUAPES	DF	F STATISTIC	PROB (X.GT.F)
MEAN	0.68802	181.775	1		
A	0.05891	1.332	1	40.523	0.C000 **
A	0.05891	1.332	1	40.523	0.0000 **
B	0.07734	2.297	1	69.859	0.C000 **
D	-0.02083	0.167	1	5.069	0.C252
CF	-0.02026	0.158	1	4.794	0.0295
CFG	-0.02865	0.315	1	9.583	0.CC22 **
CEG	-0.02812	0.304	1	9.238	0.0026 **
CEF	-0.02839	0.309	1	9.409	0.0024 **
BE	0.02328	0.208	1	6.330	0.C125 **
TCTAL FEGRESSION		188.198	10		

** INDICATES SIGNIFICANCE AT .025

where

$$X_1 = \begin{cases} +1 & \text{if 10-20 or more than 30 vehicles in kill zone} \\ -1 & \text{if less than 10 or 20-30 vehicles in kill zone} \end{cases}$$

$$X_2 = \begin{cases} +1 & \text{if more than 20 vehicles are in the kill zone} \\ -1 & \text{if less than 20 vehicles are in the kill zone} \end{cases}$$

$$X_3 = \begin{cases} +1 & \text{if the follow on force is 30-60 minutes away or no information is available.} \\ -1 & \text{if the follow on force is less than 30 or greater than 60 minutes away} \end{cases}$$

$$X_4 = \begin{cases} +1 & \text{if the enemy follow-on force is more than sixty minutes away or no information available.} \\ -1 & \text{if the enemy follow-on force is less than sixty minutes away from friendly positions} \end{cases}$$

$$X_5 = \begin{cases} +1 & \text{if the mission of the friendly force is strong-point defense} \\ -1 & \text{if the mission of the friendly force is defense in sector.} \end{cases}$$

$$X_6 = \begin{cases} +1 & \text{if artillery response time is 2-4 minutes or greater than six minutes} \\ -1 & \text{artillery response time is less than 2 minutes or 4-6 minutes.} \end{cases}$$

$$X_7 = \begin{cases} +1 & \text{if artillery response time is greater than four minutes} \\ -1 & \text{artillery response time is less than four minutes} \end{cases}$$

The model depicted here is typical of the positive and negative factors that a tactical decision-maker will have to weigh as he makes his decisions. It would, however, be very difficult to make a decision based on these factors alone. This would become apparent in a sensitivity test of the model which would require a comparison of target priority rankings by the model and another group of subjects.

J. THE CONCLUSIONS OF THE ANALYSIS

The results of the analysis clearly indicate some of the thinking that was done by the subject. The thinking of the task force commander can be modelled using the questionnaires as an experimental tool, and might possibly be done using other tools. Obviously, all of the factors were not investigated and others may have influenced the subject's decision-making process. More specifically, thirteen other factors were not investigated due to the simplification necessary to conduct an experiment using a questionnaire. These thirteen factors should be analyzed perhaps with another experimental tool. Other factors that were not investigated and often used but difficult to analyze are the map itself, the impact of terrain, and the various types and amounts of ammunitions. Time also plays an important part since the decision to mass artillery is certainly a question of timing if the results are to be successful.

In a later chapter another experimental tool will be examined. The computer wargame might possibly be able to account for some of the additional factors that go into the decision. Perhaps the computer, with its ability to store the values of more variables, will give a wargame the ability to account for other factors that now reside in the residual term of the questionnaire results.

In designing an experiment of this type the most critical factor was a sample that was representative of the population. Without the expertise that was built into the sample, none of the results would have had validity. For anyone interested in conducting an experiment of this type, it is essential that the sample size be determined in the early stages of the design. This will dictate how many variables can be analyzed and how many replications of the data it is possible to obtain. The tools for analysis are available using CPT Broussard's program.

Having discussed the analysis of a decision using a questionnaire it might be useful to draw some comparisons between other experimental tools. The next chapter will address the use of other tools in analyzing decisions and some of the advantages and disadavantages of each.

IV. A COMPARISON OF EXPERIMENTAL TOOLS

One of the desirable traits of an experimental tool to be used in analyzing decisions is realism. The more realism in the experiment, the more a subject will react to a situation as he would in a combat environment. The word real is defined as "Existing as a thing, state or quality" [Ref. 7: p. 1890]. The decision to mass fires on a kill zone occurs only in a war, which is not usable as an experimental tool. In addition, the experimenter cannot control all the variables incidental to the desired independent variables which influence the decision-maker. Realism can cause the cost of an experiment to rise rapidly. Additional personnel may be needed as data collectors and additional equipment may be necessary to support them. Even with additional personnel and equipment, the control of an experiment in a very realistic situation may be impossible.

The tools that are available to use are historical examples of a commander massing his artillery on a kill zone, a manual wargame, computer simulations, interactive computer wargames, commander post exercises and field training exercises. Each of these could be used in an analysis of a decision. Data collection should not have a high cost, so the requirement that the tool not be manpower and equipment intensive must be taken into consideration.

The interactive computer wargame has the potential to meet the requirements. It is somewhat of a compromise between the realism of war and the total experimental control of a questionnaire. The interactive computer wargame allows a player to be the tactical decision-maker in a computer-generated scenario. He can make decisions and allocate resources within the constraints of the game and is able to become involved in an environment that is more realistic than a questionnaire generated scenario. The interactive wargame is also useful in that it is capable of obtaining information (data collection), storing that information, and analyzing it without the use of additional personnel and equipment. Furthermore, it has a much lower cost than a command post exercise (CPX), or a field training exercise (FTX). A simple matrix might best explain the various experimental tools and how they might be rated against the criteria of interest. This matrix is shown in Table VI.

The element of cost is but one argument for using an interactive wargame over a CPX or an FTX. Each of the experimental tools give up realism to a degree while exhibiting potential for experimental use. A series of historical examples from battles of the past are certainly realistic, however, the accounts are based on the subjective views of the author and are frequently secondary sources of information. Seldom is combat recorded as it actually happens and seldom does it

take into account all the variables that influence a decision. A historical example is realistic but cannot be used as the only source of data for analysis.

TABLE VI

EXPERIMENTAL TOOLS AND CRITERIA FOR EVALUATION

TOOL	REALISM	COST	ANALYSIS CAPABILITY	COMPLEXITY
HISTORICAL	HIGH	LOW	LOW	VARIES
QUESTIONNAIRE	LOW	LOW	HIGH	SIMPLE
MANUAL WARGAME	HIGH	VARIES	LOW	VARIES
COMPUTER SIMULATION	MEDIUM	HIGH	HIGH	COMPLEX
COMPUTER WARGAME	HIGH	HIGH	HIGH	COMPLEX
CPX/FTX	HIGH	VERY HIGH	LOW	COMPLEX

A manual wargame is much less expensive to play. It does require a decision-maker to be skilled in the rules. It is normally time consuming and requires numerous people if it is a large, realistic game such as PEGASUS. It also requires data collectors and analysts for any experiment.

A computer simulation has assessment algorithms that are hopefully doctrinally correct and are capable of performing high speed computations and statistical analysis. However, the decision to mass fires is a human decision and the lack of man-machine interaction during the course of a scenario

degrades its usefulness for an experiment that is trying to analyze a tactical decision. The analysis of the factors that influence a human decision must start with the decision by a human. A computer simulation does not allow for this as an experimental tool.

CPX's and FTX's are conducted periodically on all major Army installations They are the most realistic of all the tools available. As previously mentioned, they are expensive and also time consuming. In terms of data collection and analysis, they present some difficulty. Normally CPX's and FTX's are used for training and operational testing. They are never replicated. The experimental procedure would be to collect data for one repetition which creates some problems for analysis. In addition, the requirements for data collectors are manpower intensive, and analysis can only be performed manually upon completion of the exercise. The possibility does exist for some experimentation to be conducted during an exercise and incidental to the exercise. This will be discussed in the last chapter.

The interactive wargame probably has the most potential for injecting realism in decision-making while exhibiting sufficient control over an experiment to allow for efficient data collection and analysis. The JANUS wargame has been chosen for this particular research based on its capability.

V. AN INTRODUCTION TO JANUS

A. A DESCRIPTION OF JANUS

JANUS was developed by the Lawrence Livermore National Laboratories associated with the University of California. JANUS may be available for student research at the Naval Postgraduate School in the near future. It is currently undergoing transition from a small computer to a much larger computer, and its capability and flexibility will be considerably increased.

JANUS is an interactive computer wargame that currently simulates combat from brigade down to item (tank section, infantry squad or howitzer section) level. JANUS is played by four players and controlled by one or two others. Two players may play the blue or allied forces and two play the red or Warsaw Pact forces. In the scenario currently being run in JANUS, the red forces are specified as Warsaw Pact motorized rifle divisions and its smallest element is a T-72 tank platton or a BMP platoon with SAGGER anti-tank missiles. The blue forces currently have an armored brigade, augmented by artillery, attack helicopters, combat engineers and additional reconnaissance assets. The player is free to choose any size element he desires to play. In addition, he may choose any of a number of combat support elements such as artillery, combat engineers, attack helicopters, and reconnnaissance elements.

The two players on each side have different tasks. One normally controls the maneuvering direct-fire weapons, while the other controls indirect fires. Each player has his own color graphics terminal (CGT) to observe the action. The game allows the players to formulate plans, organize their own forces and set up the operation, as well as pre-plan indirect fires for the operation prior to starting the game. Once the game begins, the direct fire player acts as the maneuver unit commander while the indirect fire player functions as the fire support officer (FSO).

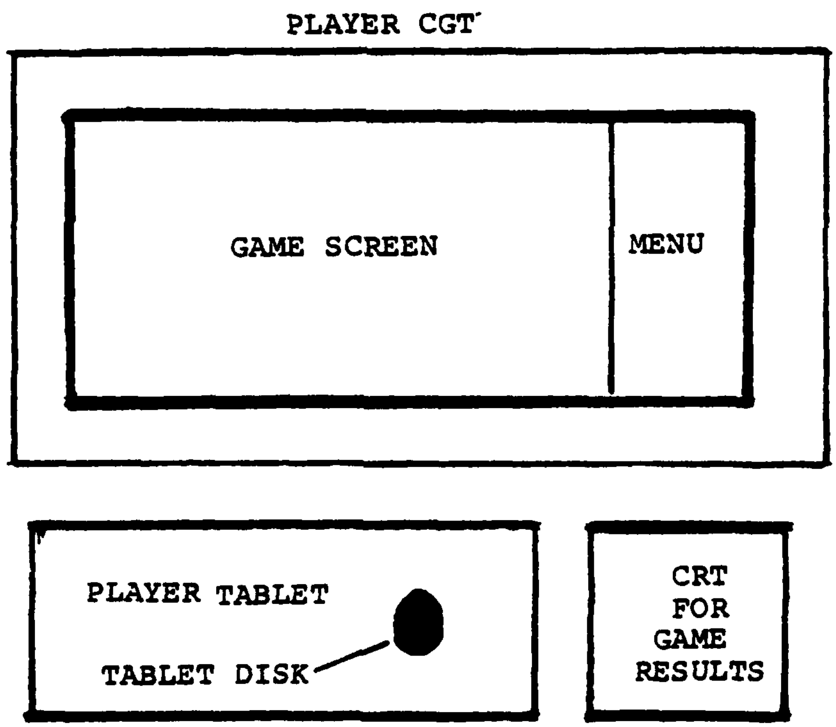

Figure 5. JANUS Workspace.

The game operation is simple. All operations are done by selecting an item from a menu which is located on the CGT next to the area of combat as shown in Figure 5. The player simply

moves the disk across the tablet which moves a corresponding cross-hair on the CGT. Once the cross-hair is on the item in the menu that is desired, the player pushes a button on the disk and then executes the appropriate procedure for the menu item selected. Personal experience of the author indicates that the mechanics of the wargame are easily learned in one or two hours.

Contact is initiated automatically when line of sight between opposing forces within the maximum range of the weapon systems has been achieved. Artillery is fired by designating a target area and physically connecting it to a battery or batteries of artillery that have been placed in support of the maneuver element during the planning of the operation. The connection is done by the indirect fire player who designates the target area with the cross-hairs on the screen, and connects it to the batteries by moving the cross-hairs over them and pushing the button on the manuever disk.

JANUS has some features that may cause difficulty in collecting and analyzing data in an experiment involving the decision to mass artillery on a kill zone. The game is designed only for two players to a side. A battalion task force has several players that may have an influence on the decision. There are provisions for playing the game with more personnel involved, but the equipment such as an intercom system required for playing with more personnel is not part of the current configuration. The direct fire engagements that a player may want to control to coordinate with

his indirect fires cannot be directly controlled. The player can control the position of the item, but the software is designed to initiate the fires of an item if its target is within range of its main armament, and the item has acquired the target. If both of these occur, the firing is done by the computer without control of the player. Indirect fires are also automatically fired once the firing battery and the target have been designated by the indirect fire player.

B. THE USE OF JANUS FOR FACTORIAL DESIGN EXPERIMENTS

The use of JANUS for experimentation should incorporate the realism of the game and the data collection and processing capabilities that can be or already have been built into the computer. In addition, the cost of such a wargame should be minimized by conducting experiments that absolutely cannot be performed by any other experimental tools that might be less costly.

In terms of analzying a decision as a function of some independent variables, a logical experiment might be to analyze a decision in terms of the variables and in terms of time. The impact of cost of the system would dictate that perhaps a wargame could be used to elaborate on the questionnaire experiment by introducing another variable (time). It makes no sense to repeat the same experiment on a multi-million dollar system that can be done using a much cheaper experimental tool.

The author attempted to design such an experiment, however, several problems arose that made the design either invalid or too costly and software intensive. It became apparent that the assumption of independence between time and any other independent variable was not valid. The only way that time could be included in this experiment was to stop the game at time increments, T_i. The values of the other independent variables, for instance, the number of vehicles in a kill zone would have a certain value at time, T_i. They would, in fact, be dependent variables on the only independent variable, time.

Recall that the procedure used in the questionnaire to arrive at the independent variables was to informally survey a sample of the population and collect their responses to what variables they would consider important in making the decision to mass artillery forces. If one were to do this for JANUS the same approach would be required. Once chosen, the independent variables would have to be implemented into the data base and a subprogram would have to be written so that each treatment is used during the game. This is all but impossible.

It must be concluded then, that because the invalidity of the assumptions of the experiment and the overriding cost of software modifications to design an experiment, full factorial experimentation to analyze a JANUS decision is impossible.

VI. CONCLUSIONS

The purpose of this thesis was to investigate an Army tactical commander's decision making process by focusing on one decision and attempting to describe the decision in terms of some independent variables. The motivation for this was to try to relate a tactical C^2 system's value to the effectiveness of a tactical unit in combat. The author contends that the tactical decision-making process, based on variables that are part of the tactical environment, fits Lawson's model of a C^2 system. This may be a point of disagreement since it follows Lawson's simplified model and therefore may tend to oversimplify a very complex process. However, the author must conclude that the basics of command and control are the authority of the commander and the decisions, which are influenced by the environment, are made to control his resources.

The experiment conducted to investigate the variables that influence the decision to mass artillery fires was completed using a questionnaire. It is concluded that this technique can be used to analyze this decision and probably can be used for other tactical decisions provided that independent variables have specific well-defined values. The questionnaire experiment, does have some disadvantages in analzying a tactical decision.

Other experimental tools such as simulations, field training exercises and command post exercises have many advantages over a questionnaire. Among them are more realism and a better capability for collecting and processing data. Disadvantages of these other experimental tools are higher cost of experimentation and less control over the factors that influence the decision.

The interactive computer wargame, JANUS, was described as a very high resolution wargame that was simple to use and had some data collection capabilities that would allow for some experimentation. However, the author attempted to design an experiment to investigate a tactical decision and found JANUS to be unsuited for such uses. The high cost of software modification would far outweigh the usefulness of a full factorial experiment. In addition, the full factorial experiment design that seemed appropriate for such an experimental tool proved faulty in that it could not meet the assumptions of the analysis.

One can conclude that more experimental tools are needed to further investigate tactical decision-making beyond the analysis found in the questionnaire experiment. If the objective of relating an improved C^2 system to improved effectiveness is still the motivation for further research, then the tools of research must become available to achieve that objective.

APPENDIX A

TACTICAL DECISION-MAKING QUESTIONNAIRE

A. INTRODUCTION

This questionnaire is designed to investigate the tactical commander's decision-making process. A tactical commander makes decisions based on various factors influencing a situation. This questionnaire will provide a means for analyzing the commander's decision-making process based on the factors that influence the situation. Not all the factors that influence a decision will be investigated. This is not an oversight but a technique to simplify the analysis of the decision.

The questionnaire focuses on a single decision: the battalion commander's decision to mass artillery on a designated trigger area or kill zone. The procedure used is to vary some of the factors that influence the decision and obtain a response based on the situation presented. Read carefully the next section which gives the general situation of the questionnaire and the assumptions inherent in the situation.

B. GENERAL SITUATION

You are the battalion/task force commander of an armored task force consisting of two tank companies and one mechanized infantry company. The task force is a part of an armored brigade in an armored division engaged in battle against Warsaw Pact forces in south central West Germany. The enemy force, presently attacking, has engaged the covering force

elements and is continuing to attack towards the division's main battle area. The Warsaw Pact forces are equipped with T-62/72 tanks, BRDM, and BMP. They are organized into their echeloned structure that is the doctrine of the Warsaw Pact.

The battalion/task force is defending in the main battle area. The direct fire weapons are M60A1/A3 tanks, Improved TOW Vehicles and Dragons. Artillery support consists of one 155mm howitzer battery in direct support of the task force. The remaining two batteries in the artillery battalion are available if the task force commander decides to mass fires on the trigger area/kill zone shown on the operations overlay. The overlay shows three companies in the task force defending from their initial battle positions. In addition, they are conducting reconnaissance to prepare subsequent positions approximately three kilometers to the south of their initial positions (shown on overlay). The plan for the defense is to destroy the enemy with a large volume of direct and indirect fires simultaneously as enemy vehicles enter the kill zone. The decision to mass artillery will be made in conjunction with a coordinated direct fire attack into the kill zone. The purpose is to concentrate fires on the enemy and disrupt the attack.

The terrain is typical of south central West Germany. Visibility is limited, however, it extends to the maximum range of all direct fire weapons. Additional assumptions are: the task force is at full strength in men and equipment,

the trigger area/kill zone is within the maximum effective range of the friendly anti-armor weapons. The task organization for the friendly forces remains the same throughout the experiment, daylight conditions exist throught the experiment; friendly forces are defending along the forward line of troops; the covering force has passed through the friendly forces who are about to engage in their initial action of the battle; the information given to the commander to make his decisions is not perfect information but reported information from his intelligence elements; artillery ammunition is sufficient to allow the artillery to support the mission of the task force; the priority of fires is to the task force; the direct support artillery has preplanned its targets on the trigger area/kill zone and has registered on the kill zone. Obstacles have been emplaced by combat engineers to channelize the enemy into the trigger area/kill zone (see overlay).

C. SPECIAL SITUATION

As the commander of TF 2-80, you have decided to position your forces in company battle positions shown on the accompanying overlay. A/2-80 armor is on battle position(BP) A, B/2-80 armor is on BP C, and C/1-76 inf (mech) is on BP B. Each company has a mission to defend from the battle position and prepare the subsequent position to its immediate south (D,E,F). The trigger area/kill zone is marked in green and has been designated on the overlay. Each of the subsequent pages will give some additional information concerning this special

situation. The information given will be divided into four separate categories. After you have read this information you will be asked two questions. The first question will require a subjective numerical response, the second question will require an answer of YES or NO. There are sixteen or seventeen situations which require answers to these two questions. When you have finished with one situation turn the page to the next. This is not a timed test. Analyze the general situation, special situation, assumptions and the additional information given on each of the questionnaires then answer the two questions based on the information given. At this time turn to the next page and begin.

TACTICAL DECISION-MAKING QUESTIONNAIRE

Read carefully the additional information. The information is listed under four separate categories. An "X" will appear in the space preceding a specific value to indicate the value for this particular situation. These will vary for each situation. Please respond to the two questions in the following manner; on the scale shown for the first question respond with a vertical line in pencil or pen at the point you decide where the appropriate answer to the question is located; an example is shown below.

10---20---30---40---50---60--|-75---80---90---100
65

The second question should be marked with an "X" in the appropriate block marked YES or NO.

ADDITIONAL INFORMATION

A. The number of enemy forces in the trigger area/kill zone is:

____ Less than 10 enemy vehicles
__X__ 10-20 enemy vehicles
____ 20-30 enemy vehicles
____ Greater than 30 vehicles

B. The intelligence report on the enemy follow-on force is:

____ A battalion to regimental size force less than 30 minutes from the task force's positions.
____ A battalion to regimental size force 30-60 minutes from the task force's present positions.
__X__ A battalion to regimental size force greater than 60 minutes from the task force's present positions.
____ No information is current available about the follow-on enemy force.

C. The mission of the friendly force is:

____ Defend in sector.
__X__ Strongpoint defense.

D. The response time for the supporting artillery is:

____ Massed Artillery on the trigger area in less than 2 minutes.
____ Massed Artillery on the trigger area in 2-4 minutes.
____ Massed Artillery on the trigger area in 4-6 minutes.
__X__ Massed Artillery on the trigger area in more than 6 minutes.

Based on the situation, assess the criticality of the information on the scale below as to whether you would fire the mass of artillery now.

10----20----30----40----50----60----70----80----90----100

Based on the situation, would you mass artillery on the trigger area now?

_____ YES __X__ NO

APPENDIX B
EXPERIMENTAL DATA

	TREATMENTS	REPLICATIONS REPL #1		REPL #2		REPL #3	
1.	(1)	0.30	NO	1.00	NO	0.69	NO
2.	G	0.50	NO	0.73	NO	0.75	NO
3.	F	0.35	NO	0.63	NO	0.30	NO
4.	FG	0.10	NO	0.85	NO	0.80	NO
5.	E	0.55	NO	0.55	NO	0.10	NO
6.	EG	0.40	NO	0.50	NO	0.80	NO
7.	EF	0.80	NO	0.65	YES	0.60	NO
8.	EFG	0.35	NO	0.85	NO	0.80	NO
9.	D	0.40	NO	0.50	NO	0.75	NO
10.	DG	0.50	NO	0.64	NO	0.80	NO
11.	DF	0.41	NO	0.50	NO	0.63	NO
12.	DFG	0.15	NO	0.54	NO	0.90	NO
13.	DE	0.35	NO	0.54	NO	0.50	NO
14.	DEG	0.50	NO	0.64	NO	0.25	NO
15.	DEF	0.16	NO	0.75	NO	0.25	NO
16.	DEFG	0.80	NO	0.76	NO	0.10	NO
17.	C	0.31	NO	0.60	NO	0.50	NO
18.	CG	0.40	YES	0.64	NO	0.80	NO
19.	CF	0.70	NO	0.91	YES	0.90	NO
20.	CFG	0.90	NO	0.65	NO	0.90	NO
21.	CE	0.45	NO	0.63	NO	0.90	NO
22.	CEG	0.50	NO	0.84	NO	0.75	NO
23.	CEF	0.30	NO	0.84	NO	0.75	NO

	TREATMENTS	REPL #1		REPL #2		REPL #3	
		REPLICATIONS					
24.	CEFG	0.50	NO	0.30	NO	0.20	NO
25.	CD	0.25	NO	0.50	NO	0.55	NO
26.	CDG	0.24	NO	0.85	NO	0.30	NO
27.	CDF	0.50	NO	0.50	NO	0.40	NO
28.	CDFG	0.85	NO	0.65	NO	0.40	NO
29.	CDE	0.20	YES	0.63	NO	0.30	NO
30.	CDEG	0.35	NO	0.85	NO	0.63	NO
31.	CDEF	0.60	NO	0.64	NO	0.50	NO
32.	CDEFG	0.15	NO	0.40	NO	0.30	NO
33.	B	0.90	YES	0.94	YES	0.75	YES
34.	BG	0.45	NO	0.76	YES	0.75	NO
35.	BF	0.50	NO	0.75	YES	0.70	YES
36.	BFG	0.76	YES	0.85	YES	0.90	YES
37.	BE	0.95	YES	0.65	NO	0.50	NO
38.	BEG	0.65	NO	0.85	YES	0.60	YES
39.	BEF	0.90	YES	0.74	YES	0.43	NO
40.	BEFG	0.75	NO	0.75	YES	0.91	NO
41.	BD	0.94	YES	0.84	YES	0.75	YES
42.	BDG	0.30	NO	0.83	YES	0.75	NO
43.	BDF	0.90	NO	0.64	NO	0.50	NO
44.	BDFG	0.50	NO	0.95	YES	0.60	NO
45.	BDE	0.61	NO	0.93	YES	0.50	NO
46.	BDEG	0.55	NO	0.75	YES	0.80	NO
47.	BDEF	0.25	NO	0.73	NO	0.80	NO

		REPLICATIONS					
	TREATMENTS	REPL #1		REPL #2		REPL #3	
48.	BDEFG	0.90	YES	0.80	YES	0.69	NO
49.	BC	0.90	YES	0.74	YES	0.45	NO
50.	BCG	0.90	YES	0.90	YES	0.50	NO
51.	BCF	0.85	YES	0.76	NO	0.80	NO
52.	BCFG	0.55	NO	0.80	YES	0.61	NO
53.	BCE	0.90	YES	0.94	YES	0.80	NO
54.	BCEG	0.40	NO	0.69	NO	0.75	YES
55.	BCEF	0.50	NO	1.00	YES	0.60	NO
56.	BCEFG	0.45	NO	0.83	YES	0.60	NO
57.	BCD	0.20	NO	0.76	YES	0.44	NO
58.	BCDG	0.60	YES	1.00	YES	0.50	NO
59.	BCDF	0.50	YES	0.85	YES	0.60	NO
60.	BCDFG	0.75	YES	1.00	YES	0.50	NO
61.	BCDE	0.90	YES	1.00	YES	0.85	YES
62.	BCDEG	0.90	YES	0.95	YES	0.70	NO
63.	BCDEF	0.90	YES	0.65	YES	0.30	NO
64.	BCDEFG	0.20	NO	0.64	NO	0.90	YES
65.	A	0.45	NO	1.00	NO	0.80	NO
66.	AG	0.65	NO	0.85	YES	0.46	NO
67.	AF	0.64	NO	1.00	NO	0.97	YES
68.	AFG	0.70	NO	0.70	NO	0.80	NO
69.	AE	0.50	NO	0.40	NO	0.50	NO
70.	A EG	0.70	YES	0.74	NO	0.40	NO
71.	A EF	0.70	YES	0.70	NO	0.90	NO
72.	AEFG	0.70	YES	0.83	YES	0.80	NO

		REPLICATIONS					
	TREATMENTS	REPL #1		REPL #2		REPL #3	
73.	AD	0.70	NO	0.94	YES	0.80	NO
74.	ADG	0.41	NO	0.75	YES	0.60	NO
75.	ADF	0.75	YES	1.00	NO	0.70	NO
76.	ADFG	0.80	NO	0.85	YES	0.70	NO
77.	ADE	0.50	NO	0.60	NO	0.80	YES
78.	ADEG	0.70	NO	0.74	NO	0.32	NO
79.	ADEF	0.55	NO	0.64	NO	0.10	NO
80.	ADEFG	0.80	YES	0.65	NO	0.90	NO
81.	AC	0.80	NO	0.75	YES	0.45	NO
82.	ACG	0.80	NO	0.75	NO	0.70	NO
83.	ACF	0.50	NO	0.50	NO	0.70	NO
84.	ACFG	0.45	NO	0.85	NO	0.50	NO
85.	ACE	0.70	NO	0.75	NO	0.90	NO
86.	ACEG	0.90	YES	0.65	NO	0.60	NO
87.	ACEF	0.60	NO	0.65	YES	0.60	NO
88.	ACEFG	0.50	NO	0.75	YES	0.42	NO
89.	ACD	0.80	YES	0.64	NO	0.50	NO
90.	ACDG	0.70	NO	0.74	YES	0.80	NO
91.	ACDF	0.90	YES	0.80	YES	0.30	NO
92.	ADDFG	0.25	NO	1.00	NO	0.50	NO
93.	ACDE	0.80	NO	0.55	NO	0.64	NO
94.	ACDEG	0.70	NO	0.64	NO	0.60	NO
95.	ACDEF	0.70	YES	0.81	YES	0.90	YES
96.	ACDEFG	0.30	NO	0.84	NO	0.40	NO

	TREATMENTS	REPLICATIONS REPL #1		REPL #2		REPL #3	
97.	AB	0.95	YES	0.84	YES	0.99	YES
98.	ABG	0.90	YES	0.85	YES	0.90	YES
99.	ABF	0.97	YES	0.85	YES	0.65	NO
100.	ABFG	0.80	YES	1.00	YES	0.80	YES
101.	ABE	0.75	YES	0.98	YES	0.80	YES
102.	ABEG	1.00	YES	0.71	YES	0.75	YES
103.	ABEF	0.90	YES	0.77	YES	0.50	NO
104.	ABEFG	0.95	YES	1.00	YES	0.80	YES
105.	ABD	0.90	YES	0.85	YES	0.20	NO
106.	ABDG	0.80	YES	0.82	YES	0.68	NO
107.	ABDF	0.96	YES	0.84	YES	0.50	NO
108.	ABDFG	0.90	YES	0.90	YES	0.55	NO
109.	ABDE	0.90	YES	0.82	YES	0.46	NO
110.	ABDEG	0.30	NO	1.00	YES	0.80	NO
111.	ABDEF	0.92	YES	1.00	YES	0.90	YES
112.	ABDEFG	0.90	YES	1.00	YES	0.90	NO
113.	ABC	0.90	YES	0.85	YES	0.55	NO
114.	ABCG	0.55	YES	1.00	YES	0.64	NO
115.	ABCF	0.80	YES	0.84	YES	0.65	NO
116.	ABCFG	0.50	YES	0.85	YES	0.65	YES
117.	ABCE	1.00	YES	0.77	YES	0.90	YES
118.	ABCEG	0.90	YES	1.00	YES	0.90	YES
119.	ABCEF	0.80	YES	1.00	YES	0.99	NO
120.	ABC EFG	0.76	YES	0.75	YES	0.95	NO

		REPLICATION					
	TREATMENTS	REPL #1		REPL #2		REPL #3	
121.	ABCD	1.00	YES	0.94	YES	0.40	NO
122.	ABCDG	0.60	YES	1.00	YES	0.80	YES
123.	ABCDF	0.70	YES	0.94	YES	0.80	YES
124.	ABCDFG	0.70	YES	0.84	YES	0.63	NO
125.	ABCDE	1.00	YES	1.00	YES	0.74	YES
126.	ABCDEG	0.93	YES	1.00	YES	0.75	YES
127.	ABCDEF	0.96	YES	1.00	YES	0.71	YES
128.	ABCDEFG	0.75	YES	0.84	YES	0.90	YES

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